New charm spectroscopy @ BaBar

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Representing the BaBar™ Collaboration

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Outline of the talk

- Charmonium spectroscopy
  - X(3870)
  - Y(4260)

- D_s spectroscopy
  - $D^*_{sJ}(2317)$
  - $D_{sJ}(2460)$
  - $D_{sJ}(2632)$

- Flash on charmed baryons

@ BaBar™

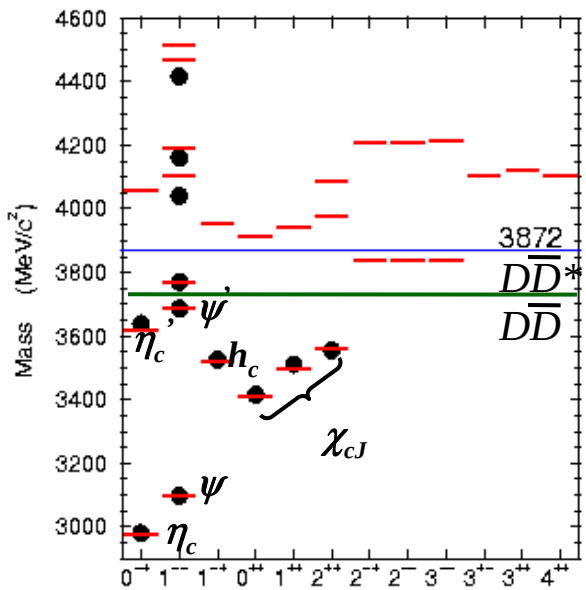
Charmonium spectrum

States below open charm threshold now well known and in agreement with potential models.

Most states above open charm threshold never seen

Other kind of states are possible (DD* molecules, diquark-antidiquark, hybrids)

New states discovered at B factories.



The X(3872) observation

- Discovered by Belle[1] in $B \to KX$, $X \to J/\psi\, \pi^+\pi^-$
- Confirmed by CDF[2], D0 [3], BABAR [4]
- $M = 3871.9 \pm 0.5$ MeV/c^2
- $\Gamma < 2.3$ MeV/c^2
- compatible [5] with $J/\psi\, \rho^0$
- $J^{PC}=1^{++}$ favoured [5]

[1] PRL 92, 262001 (2003)

[2] PRL 93, 072201 (2004)

[3] PRL 93, 162002 (2004)

[4] PRD 71, 071103 (2005)

[5] BELLE: hep-ex/0505038

What is the X(3872)?

- $B \rightarrow (c\bar{c})K$ is a typical B decay mode
- Isospin violating decay into $J/\psi\rho^0$ would be against charmonium hypothesis
- No $(c\bar{c})$ state predicted at this mass
- Exactly at $D^0\bar{D}^{*0}$ threshold [within errors]

Possible interpretations

- Charmonium [(1)(2)]
- D^0-D^{0*} molecule [(3)(4)]
- Diquark-antidiquark state [(5)]
- others…

(1) Barnes et all. , PRD 69, 054008 (2004)

(2) Eichten et all., PRD 69, 094019 (2004)

(3) Swanson, PLB 588, 189 (2004)

(4) Tornqvist, PLB 590, 209 (2004)

(5) Maiani et all., PRD 71, 014028 (2005)

Need experimental result to test models:

- Quantum numbers, decay modes, possible charged partners

$B \to X(3872)K$, $X(3872) \to J/\psi\, \pi^+\pi^-$

211 fb^{-1}

hep-ex/0507090

If $X(3872)$ is a charmonium state models predict similar production rates in B^0 and B^+ decays;

If $X(3872)$ is a $D\bar{D}^*$ molecule, models[(1)] predict suppression in B^0 decays;

If X(3872) is a tetra-quark: states produced in B^0 and B^+ decays differ and it is expected

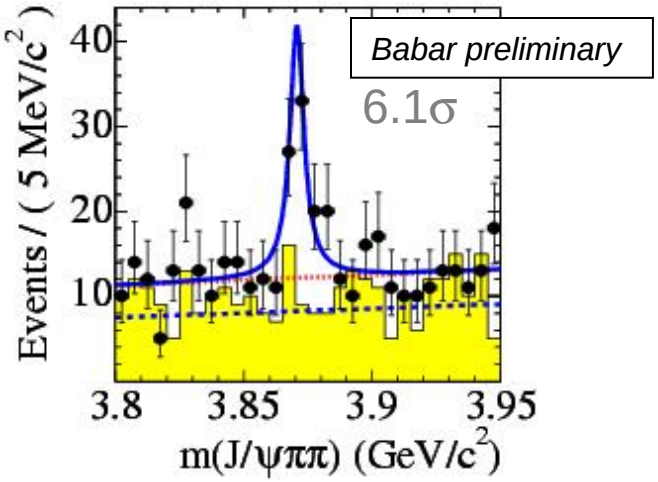
$$\Delta m \sim (7 \pm 2)\ \mathrm{MeV/c^2}$$ [(2)]

(1) Braaten and Kusunoki, PRD 71, 074005 (2005);
(2) Maiani et all. , PRD 71, 014028 (2005).

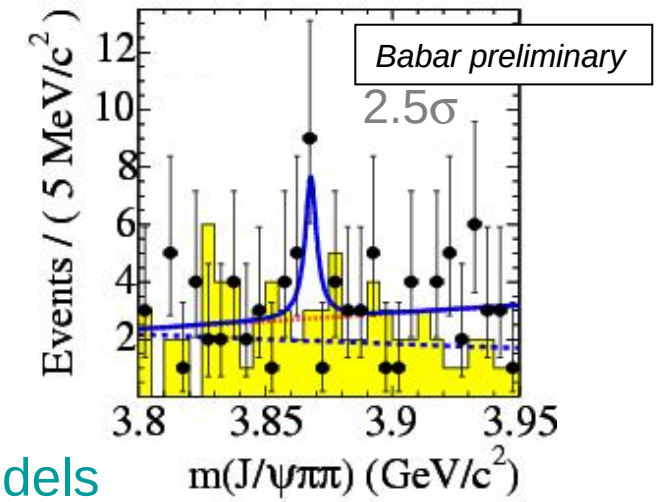
$$\frac{BR\left(B^0 \to X(3872)K^0, X(3872) \to J/\psi\pi^+\pi^-\right)}{BR\left(B^+ \to X(3872)K^+, X(3872) \to J/\psi\pi^+\pi^-\right)} = 0.50 \pm 0.30 \pm 0.05$$

$$\Delta m = (2.7 \pm 1.3 \pm 0.2)\ \mathrm{MeV/c^2}$$

$B^{\pm} \to X(3872)K^{\pm}$



$B^0 \to X(3872)K_s$



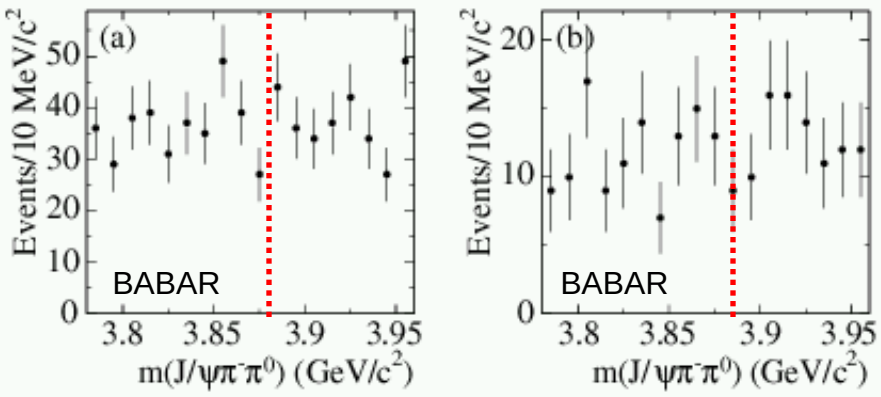
More data needed to discriminate between models

Search for X(3872) charged partners

$B^0 \to X^-(J/\psi\pi^-\pi^0)K^+$ | $B^- \to X^-(J/\psi\pi^-\pi^0)K_s$

PRD 71, 031501 (2005)

212 fb^{-1}



Isospin multiplet predicted by molecular models:

$BR(B \to X^-K) \sim 2\, BR(B \to X^0K)$

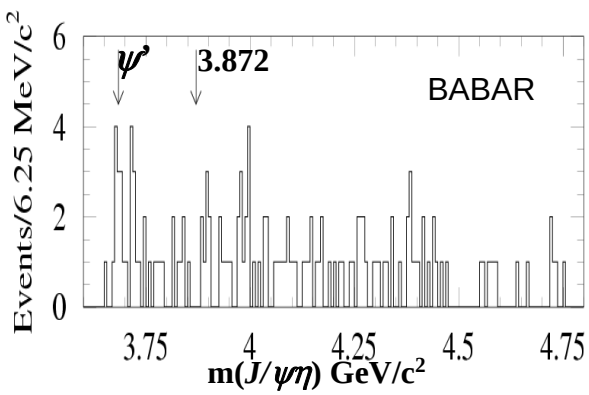
No charged partner observed

Isovectors rejected @ C.L.10^{-4}

Search for $B \to X(3872)K$, $X \to J/\psi\eta$

PRL 93, 041801 (2004)

82 fb^{-1}



Some models[1] predict large branching ratios

No signal observed

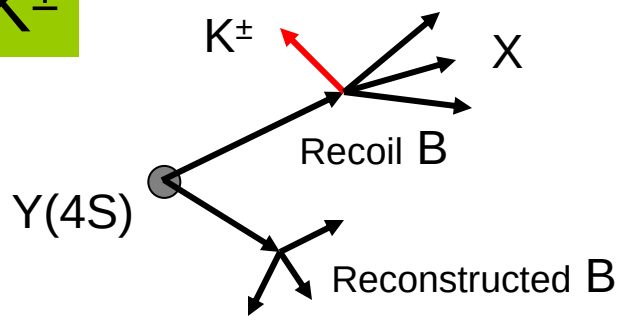
[1] PLB 574, 210

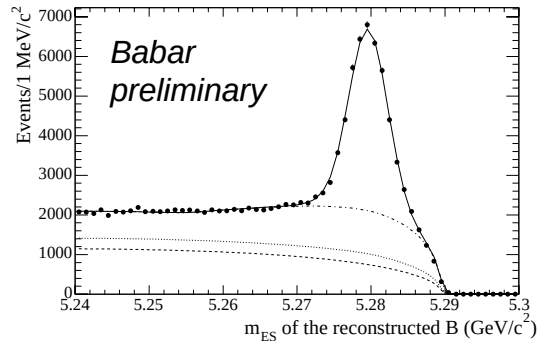
$$BR(B^+ \to X(3872)K^+, X \to J/\psi\eta) < 7.7 \times 10^{-6}, 90\%\ \text{C.L.}$$

Inclusive charmonia in B decays

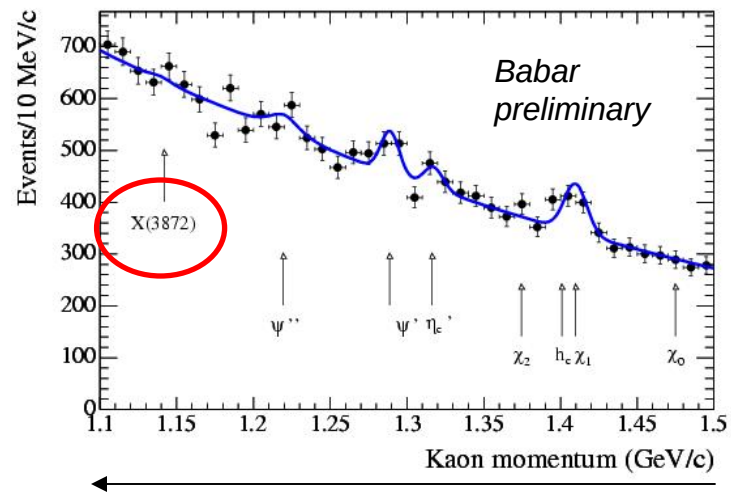
210 fb^{-1}

$B^{\pm} \rightarrow X_{c\bar{c}} K^{\pm}$





Novel variation on the recoil technique
Measurement of the $K^{\pm}$ momentum spectrum in B center-of-mass frame



Recoil Mass

No signal is observed for $B^{+} \rightarrow X(3872)K^{+}$:

$BR(B^{+} \rightarrow X(3872)K^{+}) < 3.2 \times 10^{-4} \Rightarrow$

$BR(X(3872) \rightarrow J/\psi \pi^{+} \pi^{-}) > 4.2\%$, 90% C.L.

No signal is observed for charged partners in $B^{0} \rightarrow X(3872)^{+}K^{-}$:

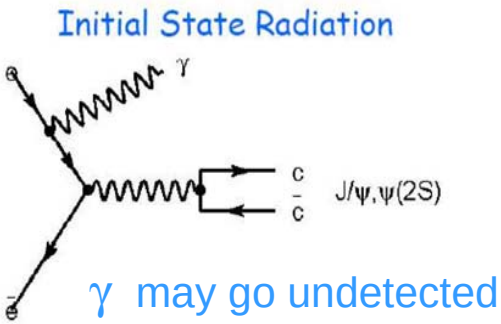
$BR(B^{0} \rightarrow X(3872)^{+}K^{-}) < 5 \cdot 10^{-4}$ at 90% C.L.

χ_{c1}, ψ', ψ'' and η_c' BR compatible with exclusive measurements

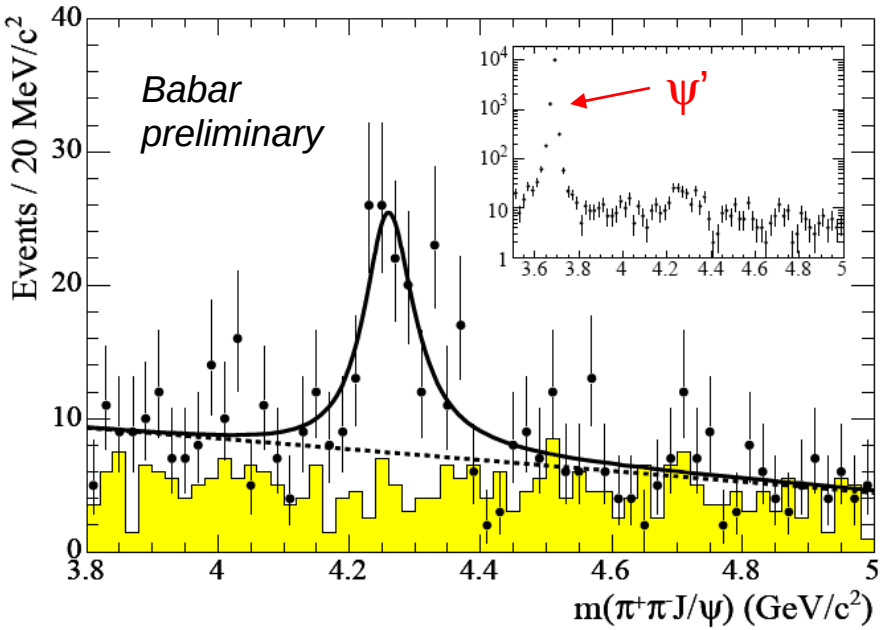
The Y(4260) observation

233 fb^{-1}

Phys.Rev.Lett. 95, 142001 (2005)



$e^+e^- \to \gamma_{ISR}\ J/\psi(l^+l^-)\ \pi^+\pi^-$



No X(3872) evidence.

No ψ(4040), ψ(4160), ψ(4415).

Observed (>8σ) a broad structure Y(4260):

$N = 125 \pm 23$

$M = 4259 \pm 8^{+2}_{-6}$ MeV/c^2

$\Gamma = 88 \pm 23^{+6}_{-4}$ MeV/c^2

$\Gamma(Y \to e^+e^-) \cdot BR(Y \to J/\psi\pi^+\pi^-) = 5.5 \pm 1.0^{+0.8}_{-0.7}$ eV/c^2

$J^{PC} = 1^{--}$

Impossible to distinguish between 1 or more resonances.

Search for Y(4260) in B decay

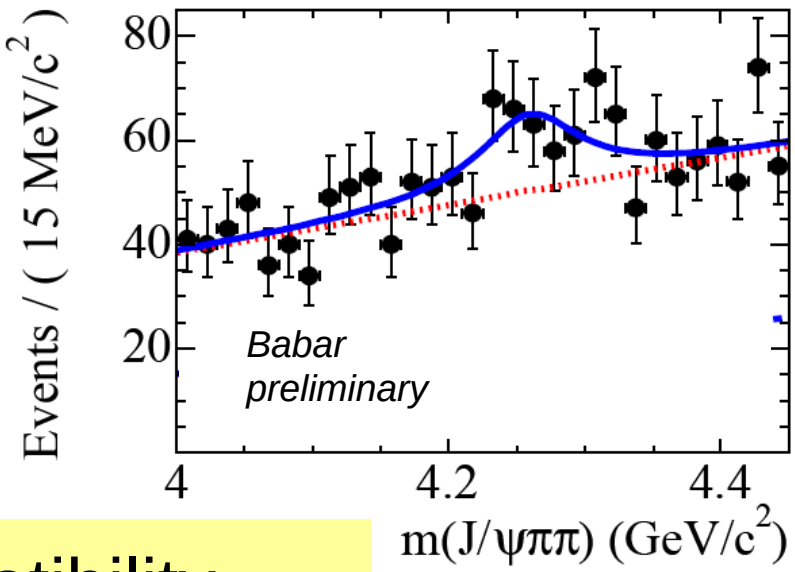
211 fb^{-1}

hep-ex/0507090

$B^{\pm} \to Y(4260)K^{\pm}; Y(4260) \to J/\psi\, \pi^+\pi^-$

Excess of event at 4260 MeV:

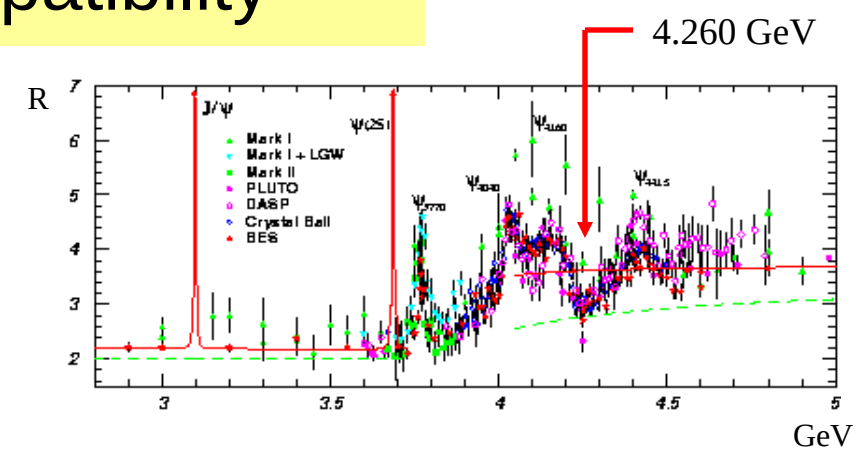
- M, Γ fixed to the ISR analysis values
- N = 128 ± 42 events
- Significance: 3.1σ
- $BR(B^- \to YK^-) \cdot BR(Y \to J/\psi\pi^+\pi) = (2.0 \pm 0.7 \pm 0.2) \times 10^{-5}$



R measurements compatibility

$\sigma(e^+e^- \to Y(4260) \to J/\psi\, \pi^+\pi^-)$ at level of 4% $\sigma(e^+e^- \to hadrons)$

$BR(Y \to J/\psi\, \pi+\pi-)$ must be large despite state above $D(*)\bar{D}(*)$ threshold



Charmonium summary

- X(3872) [1]
  - Observed in neutral and charged B decay:
    - $B \rightarrow X(3872)K$, $X(3872) \rightarrow J/\psi\pi^+\pi^-$
  - BR($X(3872) \rightarrow J/\psi\pi^+\pi^-$)>4.2% @ 90% C.L.
  - No isovector charged partners observed
  - No $X(3872) \rightarrow J/\psi\eta$ decay observed
  - Not seen in ISR events

- Y(4260) consistent with assignment $J^P=1^{--}$:
  - recently observed by Babar in ISR events
  - evidence for $B^\pm \rightarrow Y(4260)K^\pm$ decay
  - statistic do not allow to distinguish between one or more state hypotheses

- Further investigations are needed to understand the nature of these states.

[1] BELLE favour $J^P=1^{++}$ assignment.

New charmed mesons

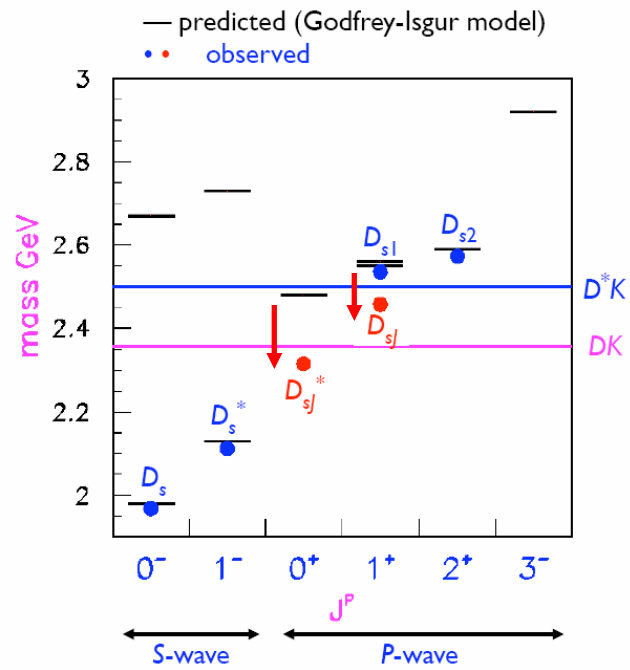
Four states known before B-factories data
$D_s(1968)^+$, $D_s^*(2112)^+$, $D_{s1}(2536)^+$, $D_{s2}^*(2573)^+$
in good agreement with theoretical predictions.

Two new states discovered by *BABAR*[1] and CLEO[2]: $D_{sJ}^*(2317)^+$ (into $D_s^+\pi^0$), $D_{sJ}(2460)^+$ (into $D_s^{*+}\pi^0$).

Missing 0^+,1^+ states?
- Masses significantly lower than predictions.
- Isospin violation decay.

SELEX[3] reported a state at M= 2632 MeV decaying into $D_s^+\eta$ and D^0K^+.

Other possible interpretations?
- tetraquark[4] or molecules[5].



Quantum numbers needed

[1] PRL 90, 242001; [2] PRD 68, 032002; [3] PRL 93, 242001.

[4] PRD 71, 014028; [5] PRD 68, 054006

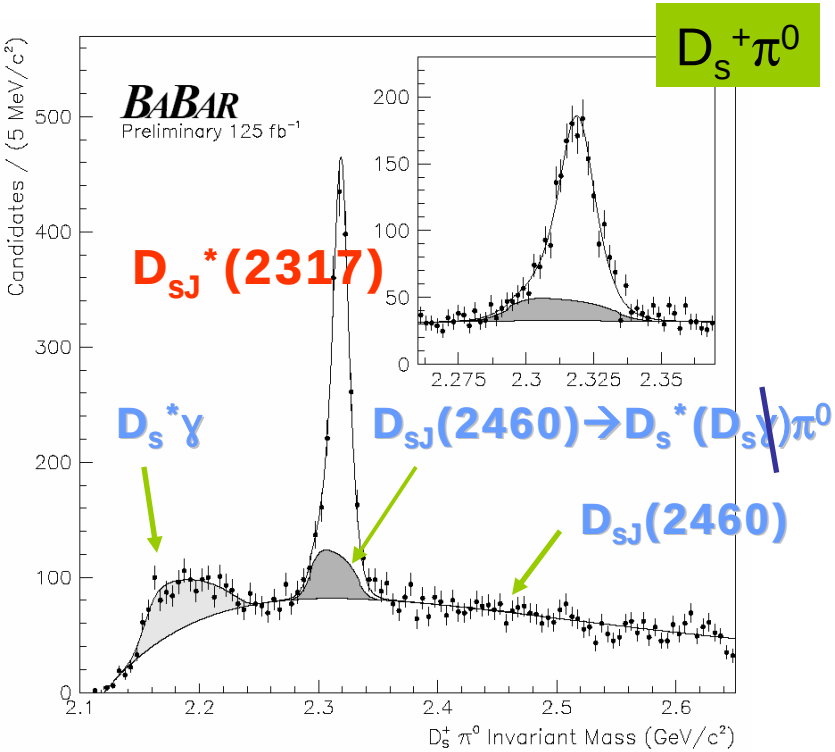
$D_{sJ}^*(2317) \rightarrow D_s\pi^0$ and $D_{sJ}(2460) \rightarrow D_s^*\pi^0$

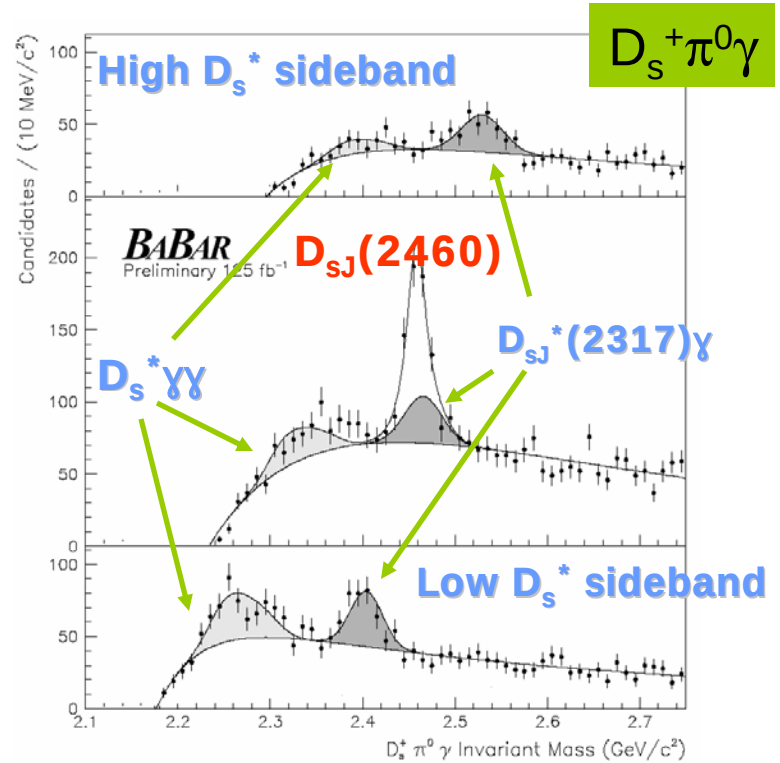
123 fb^{-1}

$e^+e^- \rightarrow D_{sJ}^*(2317)^+ + X$ hep-ex/0408067 $e^+e^- \rightarrow D_{sJ}^*(2460)^+ + X$

$\hookrightarrow D_s^+\pi^0$ $\hookrightarrow D_s^{*+}(D_s^+\gamma)\pi^0$

$D_s^+ \rightarrow \phi(K^+K^-)\pi^+, K^+K^{*0}(K^-\pi^+)$ $D_s^+ \rightarrow \phi(K^+K^-)\pi^+, K^+K^{*0}(K^-\pi^+)$





$m(D_{sJ}^*(2317)) = 2318.9 \pm 0.3(\text{stat.}) \pm 0.9(\text{syst.})$ MeV/c^2 *(below $D^{(*)}K$ threshold)*

$m(D_{sJ}(2460)) = 2459.1 \pm 1.3(\text{stat.}) \pm 1.2(\text{syst.})$ MeV/c^2 *(below D^*K threshold)*

More $D_{sj}^{(*)}$ decay modes

123 fb^{-1}

hep-ex/0408067

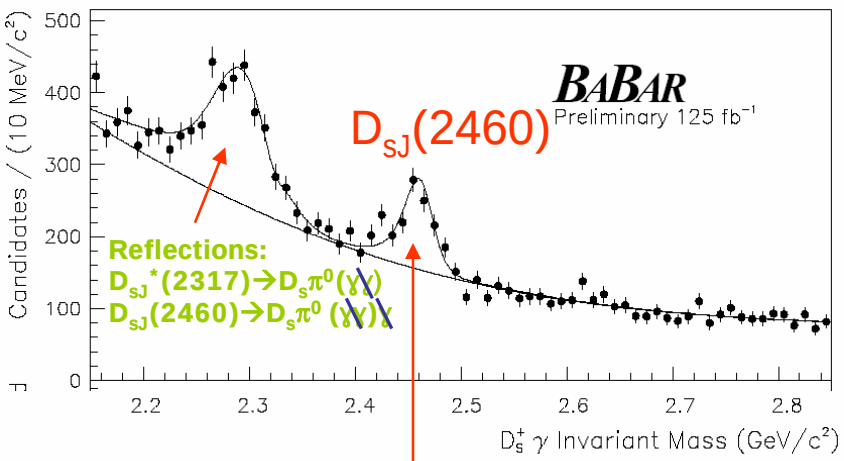
Assuming parity conservation:

$$D_{sJ}^{*}(2317)^{+} \to D_s^{+}\pi^0 \Rightarrow J^P = 0^+, 1^-, 2^+, 3^- \ldots$$

$$D_{sJ}(2460)^{+} \to D_s^{*+}\pi^0 \Rightarrow \begin{cases} S-\text{wave} \Rightarrow J^P = 1^+ \\ P-\text{wave} \Rightarrow J^P = 0^-, 1^-, 2^- \end{cases}$$

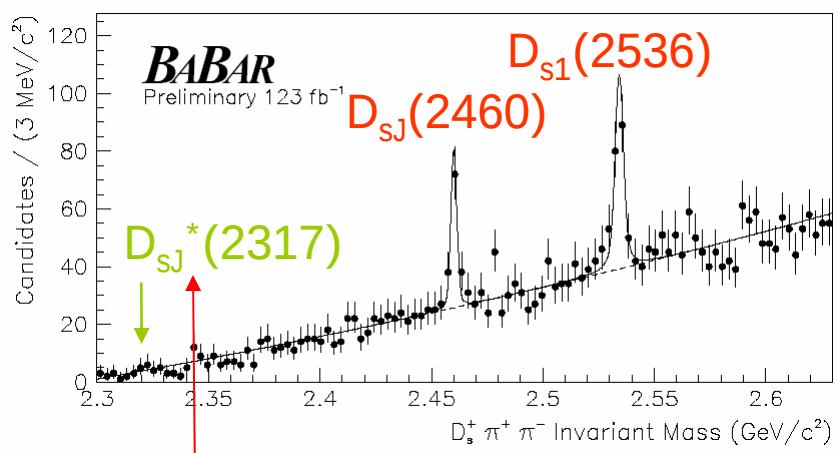
Search for radiative and dipion transitions in order to confirm or rule out some of these hypotheses

$D_s^+\gamma$ ($J^P=1^\pm,2^\pm,\ldots$)



$D_{sJ}(2460) \to D_s\gamma$ excludes $J^P = 0^\pm$

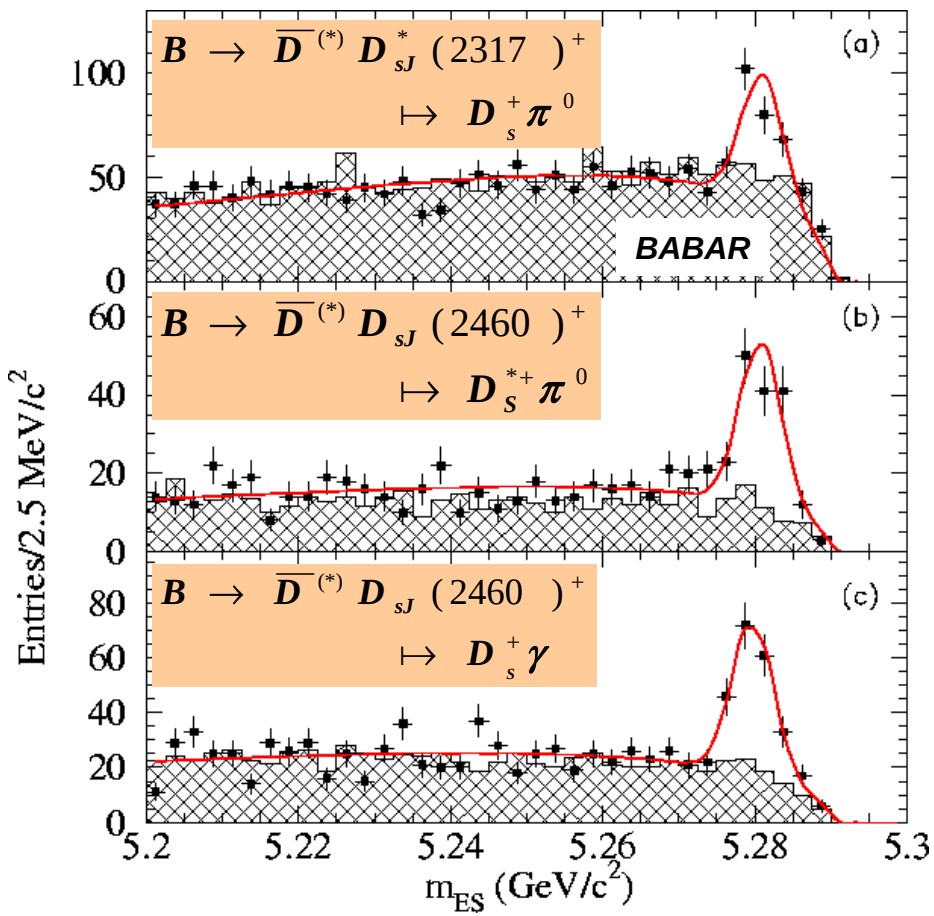
$D_s^+\pi^+\pi^-$ ($J^P=0^-,1^\pm,2^\pm\ldots$)



Absence consistent with $J^P = 0^+$; allowed for all other parity

Observation of $B \to \overline{D}^{(*)} D_{sJ}^{(*)}$

113 fb^{-1}



Side bands $m(D_{sJ}^{(*)})$

fit results

Phys.Rev.Lett. 93, 181801 (2004)

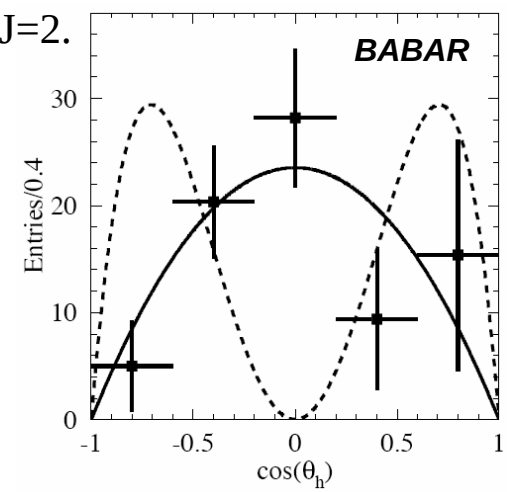
$$\frac{BR(D_{sJ}(2460)^{+} \to D_s^{+}\gamma)}{BR(D_{sJ}(2460)^{+} \to D_s^{*+}\pi^0)} = 0.274 \pm 0.045 \pm 0.020$$

Compatible with predictions from:

Bardeen et all., Phys.Rev. D68, 054024 (2003)

- $D_{sJ}(2460)$ produced with helicity 0 in $B \to \overline{D}\, D_{sJ}$.

θ_h helicity angle for $D_{sJ}(2460) \to D_s\gamma$:
Solid line expectation for J=1, dotted line expectation for J=2.



J=1 preferred

Search for SELEX $D_{sJ}(2632) \rightarrow D_s\eta$, D^0K^+

125 fb^{-1}

hep-ex/0408087

- $D_s^+ \rightarrow \phi(1020)\pi^+$, $K^*(892)^0K^+$
- $\eta \rightarrow \gamma\gamma$ where
  - ✓ $\gamma \notin \pi^0 \rightarrow \gamma\gamma$
  - ✓ $\gamma \notin D_s^{*+} \rightarrow D_s^+\gamma$

$$e^+e^- \rightarrow D^{*+} + K_s^0 + X$$

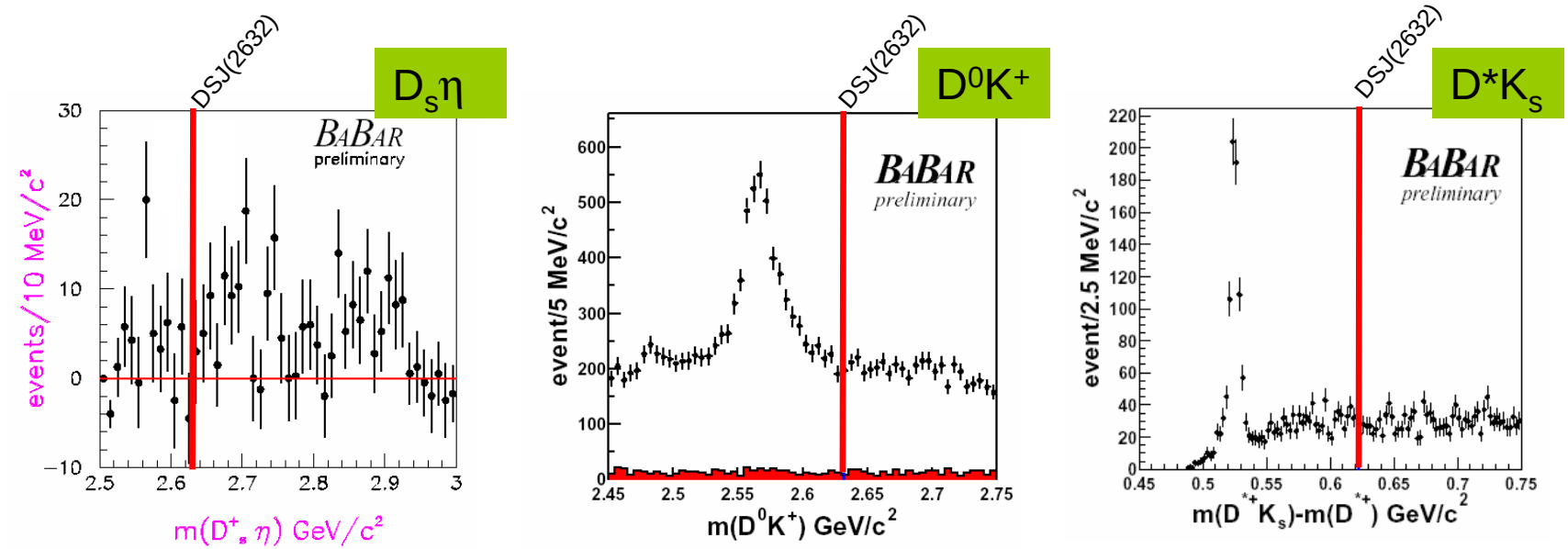
$$K_s^0 \rightarrow \pi^+\pi^-$$

$$D^{*+} \rightarrow D^0\pi^+$$

$$D^0 \rightarrow K^-\pi^+$$

$$e^+e^- \rightarrow D^0 + K^+ + X$$

$$D^0 \rightarrow K^-\pi^+$$



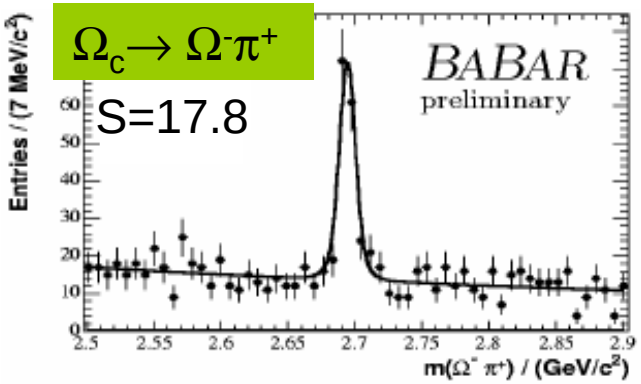
BaBar sees no evidence for $D_{sJ}(2632) \rightarrow D_s\eta$, D^0K^+, $D^{*+}K_s$

D_{sJ} mesons summary

- $D_{sJ}^*(2317)$ consistent with assignment $J^P=0^+$:
  - *observed in $D_s \pi^0$ system*
  - *not seen in $D_s \gamma$ or $D_s \pi^+ \pi^-$*
- $D_{sJ}(2460)$ consistent with assignment $J^P=1^+$:
  - observed in $D_s^* \pi^0$, $D_s \gamma$, $D_s \pi^+ \pi^-$
  - helicity in $B \to \overline{D} D_{sJ}(2460)$ decays consistent with J=1
- No evidence for isovector $D_{sJ}^*(2317)$ partners
- No evidence for $D_{sJ}(2632)$ state

Evidence so far points out that D_{sJ} may be interpreted as two ordinary $c\bar{s}$ mesons; yet the low mass of the D_{sJ} states has still to be understood.

New results on charmed baryons



Λ_c baryons [1] :

[1] hep-ex/0507009

- High precision mass measurement of Λ_c making use of the decays $\Lambda_c^+ \to \Lambda^0 K_s K^+$, $\Lambda_c^+ \to \Sigma^0 K_s K^+$

Ω_c baryons [2] :

[2] hep-ex/0507011

- Studied decay channels: $\Omega_c \to \Omega^- \pi^+$, $\Omega^- \pi^+ \pi^- \pi^+$, $\Xi^- K^- \pi^+ \pi^+$
- Measurement of branching fraction ratios
- First observation in a single decay channel with significance >5σ
- First observation of production in B decays

Ξ_c baryons [2] :

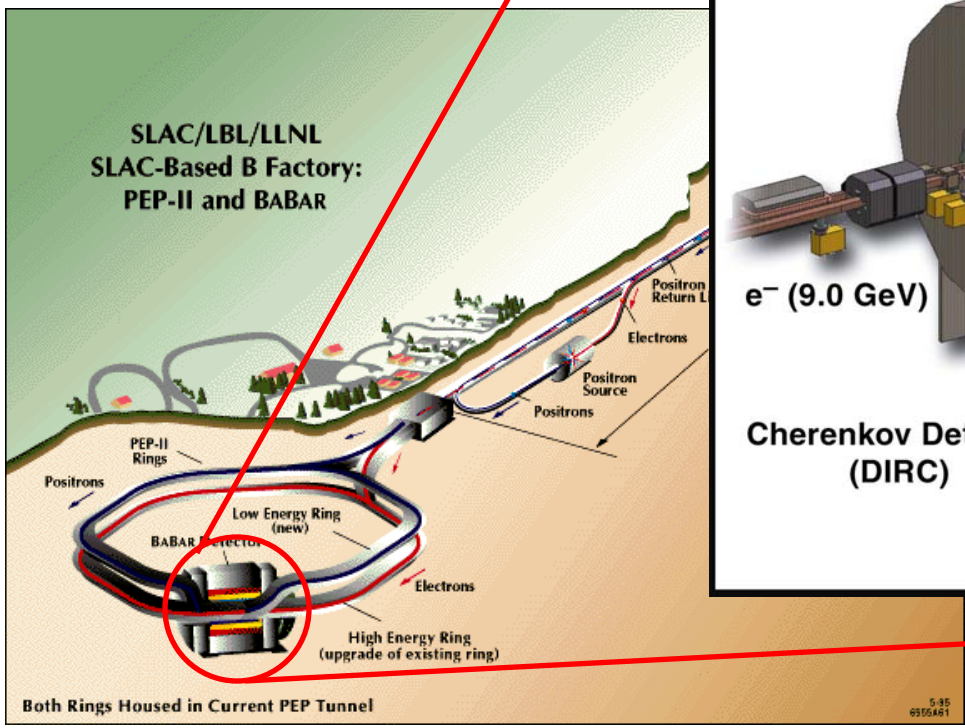
[3] Phys.Rev.Lett. 95, 142003 (2005)

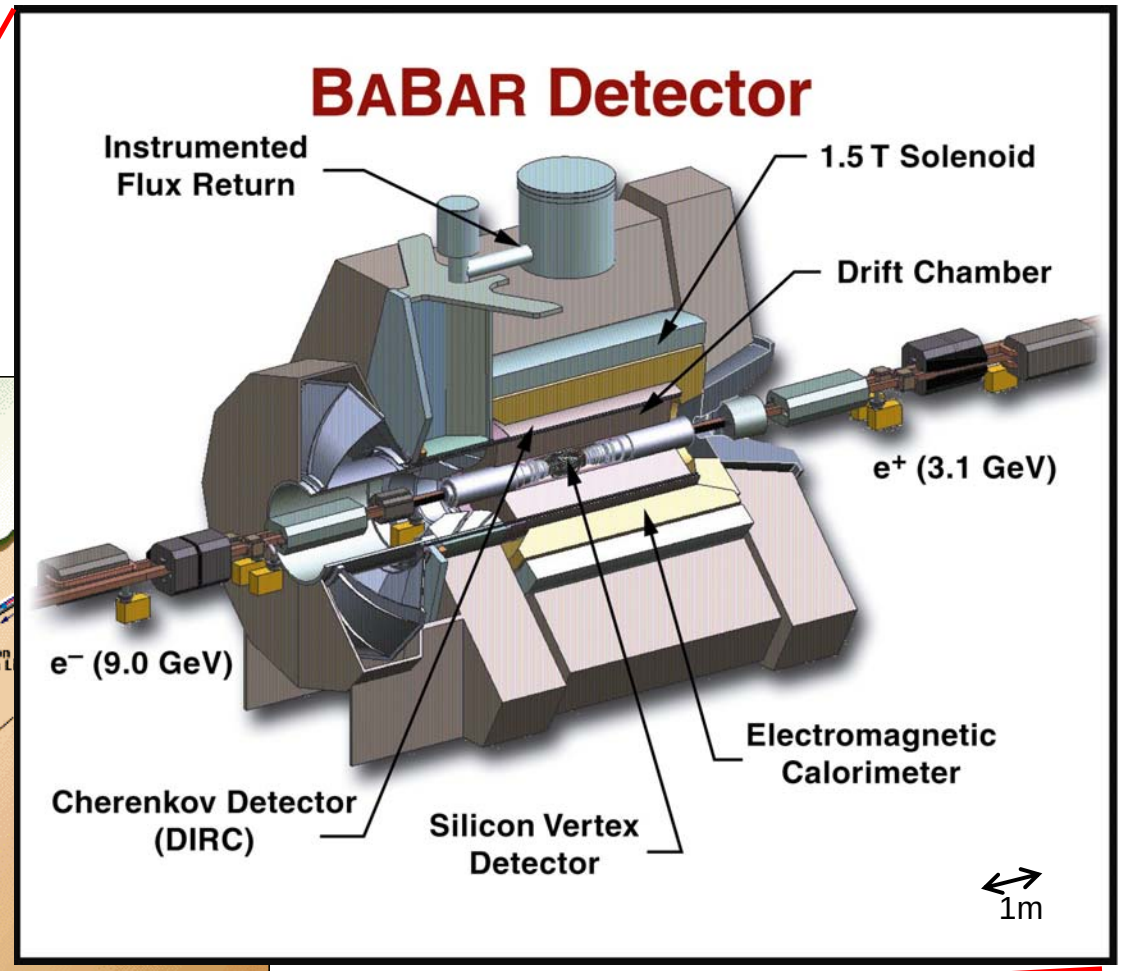
- Studied decay channels: $\Xi_c \to \Omega^- K^+$, $\Xi^- \pi^+$
- Measurement of branching fraction ratios
- Studies of production from continuum
- Studies of production from B decays

Backups

BaBar detector

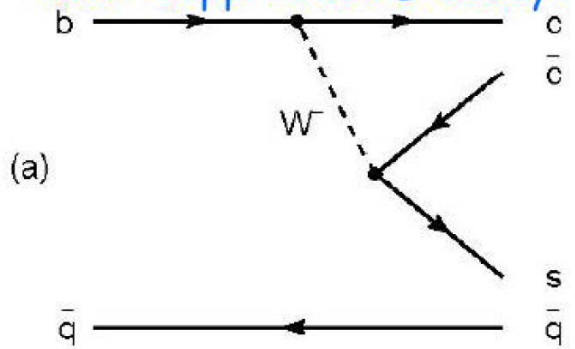
SVT:
97% efficiency – 20μm z resol
SVT+DCH:
$\sigma(p_t)/p_t = 0.13\% \cdot p_t + 0.45\%$
EMC:
$\sigma(E)/E = 2.32\% \cdot E^{-1/4} + 1.85\%$



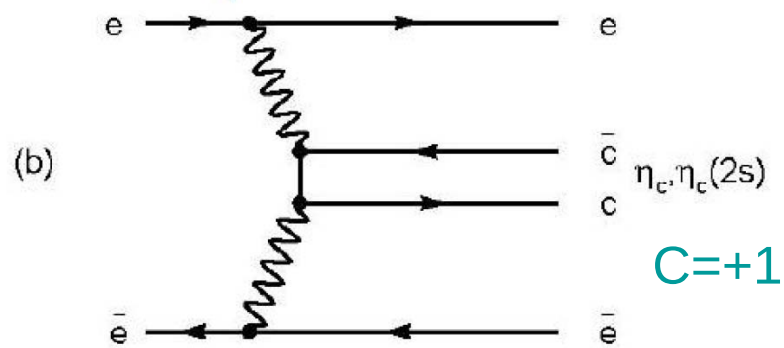


Experimental technique

Color suppressed B decays

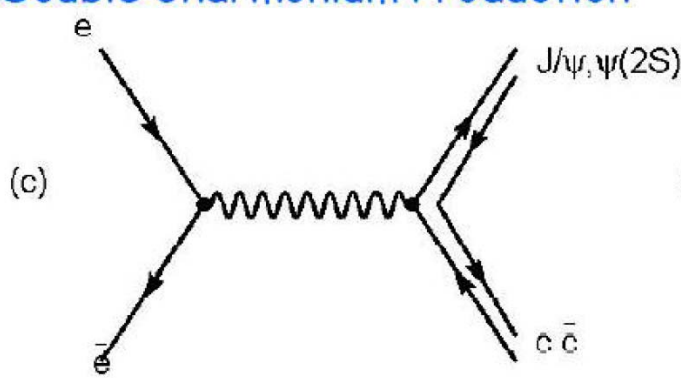


Two photon Production

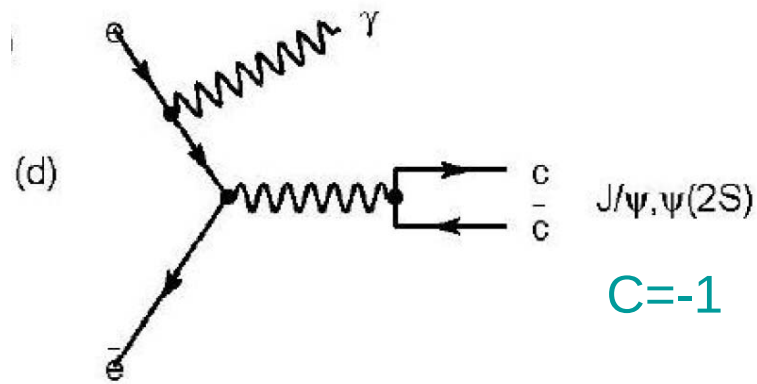


C=+1

Double Charmonium Production



Initial State Radiation



C=-1